MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2016/2017

EEE2056 – PHYSICAL ELECTRONICS

(All sections/Groups)

11 MARCH 2017
2.30 p.m - 4.30 p.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.

2. Attempt **All** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

Useful constants and coefficients:

Physical Constants

Boltzmann's constant (k)	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant (h)	6.626×10^{-34} Js
Thermal voltage@300K kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space (m_e)	9.10939×10^{-31} kg
Electron charge (e)	1.60218×10^{-19} C
Effective density of states in the conduction band for Si (N_c)	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band for Si (N_v)	1.2×10^{19} cm^{-3}
Permeability of free space (μ_0)	$4\pi\times10^{-7}$ Hm^{-1}
Permittivity of free space of free space (ε_0)	8.85×10^{-12} Fm^{-1}
Avogadro's number (N_A)	6.022×10^{23} atoms/mol

Question 1

(a) The interaction of light with electrons in a material, namely the photoelectric effect as illustrated in Figure Q1(a) was successfully interpreted by Einstein based on Planck's idea of energy quanta or proton.

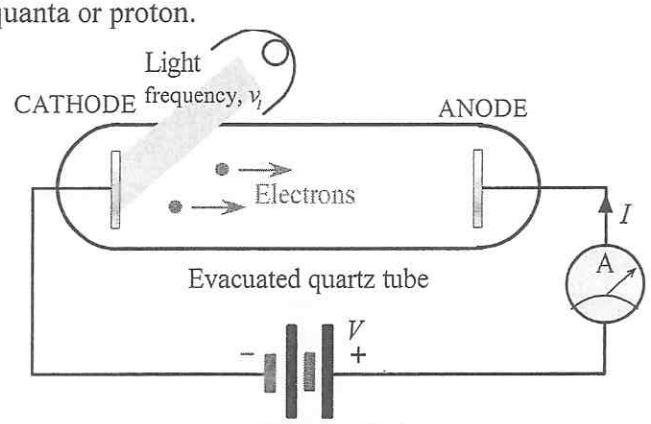

Figure Q1(a)

(i) Sketch the relationship between the photo-generated electric current (*I*) and the applied voltage (*V*) (positive and negative biases) of the experiment as shown in Figure Q1(a). In your diagram, indicate the stopping voltage, *Vs*.

[3 marks]

(ii) Sketch the photoelectric current, *I*, as a function of applied bias, *V* if the material is illuminated with light of a higher frequency, $\nu_2 > \nu_1$.

[3 marks]

(b) Using the Schrödinger wave equation $-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2}+V(x)\psi(x)=E\psi(x)$ to show that all values of energy are allowed for an electron in free space. Sketch the energy versus momentum diagram of the electron.

[5 marks]

(c) (i) Show that a free electron confined in a one-dimensional infinite potential well is quantized and its energy is given by $E=\frac{\hbar^2\pi^2n^2}{2mL^2}$, where n = 1, 2, 3, ... and L is the width of the well.

[8 marks]

(ii) Given that the width of the infinite potential well L = 2.5 nm, determine the wavelength of the emitted photon when an electron drops from the third energy level to second level.

[6 marks]

Continued....

Question 2

(a) Electrons are the "glue" that hold the nuclei in a material together via different types of bonding.

(i) What are the THREE primary bonds in solids? [1.5 marks]

(ii) Briefly explain the Van der Waals bond in a solid and give an example. [2.5 marks]

(b) The electron distribution at temperature T in a metal is described by the Fermi-Dirac distribution function.

(i) State the Fermi-Dirac probability function. [2 marks]

(ii) Briefly explain why electron in a metal is unlike neutral gas. [3 marks]

(iii) Determine the electron probability of occupancy in a metal at 0.25 eV above its Fermi energy, E_F at room temperature 27°C. [3 marks]

(iv) Sketch the distribution of electrons in the metal at different temperatures $T_2 > T_1 > 0K$ together with Fermi-Dirac distribution at 0 K. Explain your diagrams. [6 marks]

(c) Figure Q2(c) shows the energy-band splitting of silicon as a function of lattice spacing.

(i) Write down the electronic configurations of Si. [2 marks]

(ii) Explain how the energy band is formed in Si and name the upper and lower bands at equilibrium lattice spacing, a_o. [5 marks]

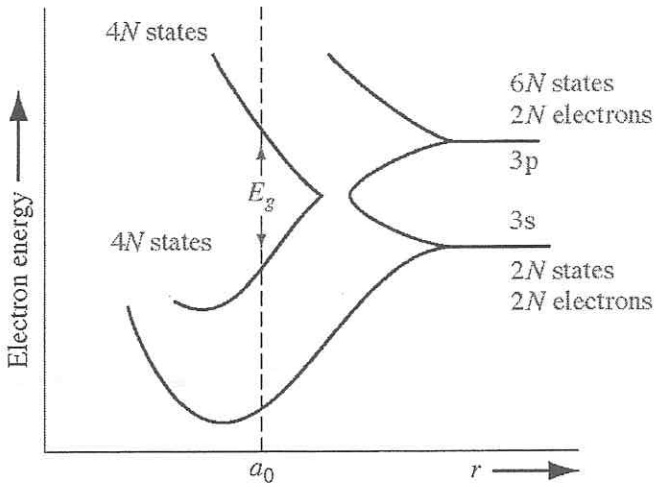

Figure Q2(c)

Continued....

Question 3

(a) In the Kronig-Penney model, the time-independent Schrödinger equation is solved to obtain the allowed values of energy E as a function of wavenumber k. Using the concept of wavepacket within a crystal, show that a quantum mechanical quantity namely effective mass can be deduced from the E-k diagram. [7 marks]

(b) Figure Q3(b) shows the E-k diagram of GaAs. In the conduction band, there are THREE valleys namely Γ-valley, L-valley and X-valley. The valence bands are Heavy holes, Light holes and Split-off band.

(i) Electrons in which valley will have heavier effective mass, Γ-valley or L-valley and why? [3 marks]

(ii) GaAs is a direct or indirect bandgap semiconductor. Explain your answer. [2 marks]

(iii) Briefly explain the thermal generation of electron-hole pairs in a pure GaAs semiconductor. [3 marks]

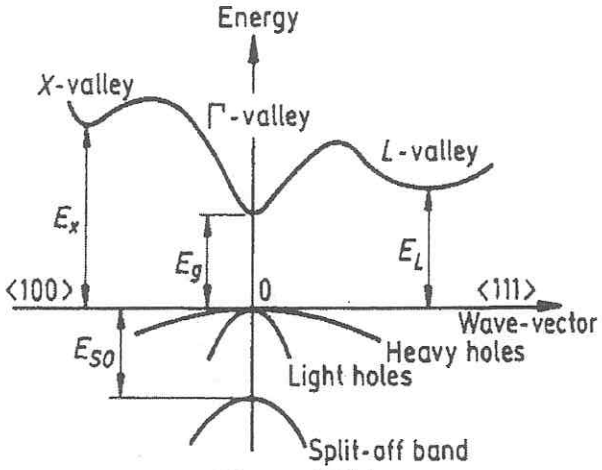

Figure Q3(b)

(c) At applied electric field of 15 V/cm, a drift current density of 280 A/cm^2 is measured in a particular semiconductor device using n-type GaAs. Given that the mobility of electron and hole in GaAs are 8500 cm^{2}V^{-1}s^{-1} and 400 cm^{2}V^{-1}s^{-1}, respectively and the intrinsic concentration $n_i = 2.1\times10^6$ cm^{-3} at 300 K.

(i) Determine the doping density in GaAs. State the assumptions in your calculation. [5 marks]

(ii) If this n-type GaAs is further doped with 10^{15} cm^{-3} acceptor atoms, what is the required applied electric field to produce the same drift current density? [5 marks]

Continued....

Question 4

(a) Figure Q4(a) shows the energy band diagram of a semiconductor PN junction at equilibrium condition.

(i) Explain why the Fermi level is constant throughout the PN junction. [2 marks]

(ii) Show that the built-in potential voltage V_{bi} can be expressed in terms of doping density in the P- and N-type semiconductors (N_A and N_D), intrinsic carrier density (n_i) and temperature (T) in the PN junction as $V_{bi} = \frac{kT}{q} \ln\left[\frac{N_A N_D}{n_i^2}\right]$. [7 marks]

(iii) Sketch the energy band diagram of the PN junction under forward and reverse biases. Explain the current conduction under these conditions. [8 marks]

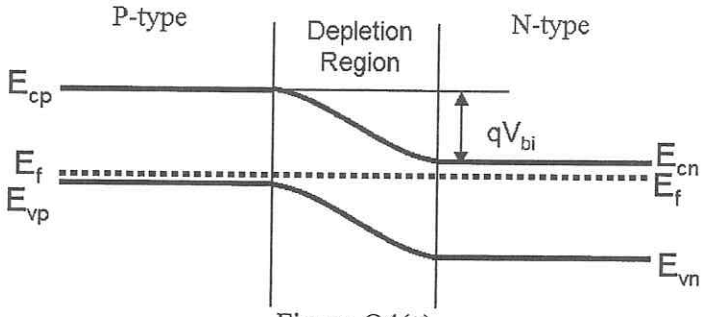

Figure Q4(a)

(b) A PN diode made from silicon with doping concentration of $N_A = 6\times10^{17}\,\text{cm}^{-3}$ on the P-side and $N_D = 3\times10^{16}\,\text{cm}^{-3}$ on the N-side is fabricated to produce 25 mA forward current at applied voltage of V = 0.45 V. Given that the intrinsic concentration, $n_i = 1.5\times10^{10}\,cm^{-3}$ at room temperature 27 °C.

(i) Calculate the built-in voltage across the PN junction of the diode. [3 marks]

(ii) Calculate the diode reverse saturation current. [3 marks]

(iii) Calculate the diode current at applied bias of -12 V. [2 marks]

End of the paper